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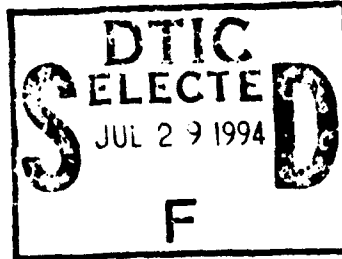
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PROSPECTS OF USING RADIOACTIVE ISOTOPES AND NUCLEAR
RADIATION IN METALLURGY AND OTHER TECHNICAL SCIENCES

- USSR -

by A. M. Samarin and M. S. Fomichev

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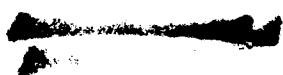
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FOREWORD

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PROSPECTS OF USING RADIOACTIVE ISOTOPES AND NUCLEAR
RADIATION IN METALLURGY AND OTHER TECHNICAL SCIENCES

[Following is a translation of an article by A. M. Samarin and M. S. Fomichev in the Russian periodical Izvestiya Akademii nauk SSSR, Otdeleniye tekhnicheskikh nauk, Metallurgiya i toplivo (Bulletin of the Academy of Sciences USSR, Department of Technical Sciences, Metallurgy and Fuels), No 6, 1959, Moscow, pages 121-126.]

Radioactive isotopes and nuclear radiation are widely used in scientific research institutes, factory laboratories, and industrial enterprises in work connected with the most important economic problems in prospecting for and extracting minerals, metallurgy and metalworking, machine building, equipment manufacturing, controlling and automatizing technological processes, enriching ores, and numerous processes in hydrodynamics, ground mechanics, and other technical fields.

In the field of prospecting for and extracting natural resources, the broadest and most varied application of these methods is found in the petroleum industry. Using polonium and beryllium sources of radiation in the neutron sampling of oil wells, the oil industry has organized the serial output of apparatus for radioactive methods of well sampling and introduced this apparatus in over 150 industrial geophysical places. At present new models of well equipment with neutron proportional counters have been designed. In addition, there is equipment for measuring in wells with high temperatures, permitting the recording of qualitative diagrams with a temperature of the surrounding strata of up to 150-200°C; equipment with scintillation counters, superior in intensive measurement and in broader spectral sensitivity to the equipment with digit counters previously used; and two-channel equipment with boric fluid for determining the position of water-oil surface.

The experiments conducted in 1959 with an impulse well generator of neutrons in oil wells in Bashkiriya demonstrated its great advantage over the usual neutron sources. Specifically, upon the application of the impulse generator, the oil-water surface is repulsed by changes repeated 7 to 10 times in radiation value, and the influence of the borehole is substantially reduced, which permits a more accurate determination of porosity, oil-gas saturation, etc.

Radioactive isotopes are also widely used in petroleum extraction, primarily in studying the technical conditions of wells: determining the height of the rise of cement solution in the column and the quality of cementation; determining sections of the protective circulation of water, points of pipe damage, zones of the absorption of drilling solution, etc.

Further research in this direction is necessary for improving and developing radiometric apparatus and designing even more sensitive instruments for the registration of gamma quanta and neutrons of different energies.

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energies, measured in work under high temperatures. A great amount of attention is being given to dispersed gamma-ray methods, the neutron method, and gamma spectroscopy. These methods assure a more accurate determination of the lithography of the strata surrounding a well and are used in the investigation of the porosity, oil saturation, and gas saturation of reservoirs.

In prospecting for coal deposits, the method has been developed of locating coal layers by means of intensive dispersed gamma radiation from the isotope of cobalt-60, placed beside a counter shielded from the direct action of the gamma rays in a special steel capsule. By maintaining the proper distance between the source of primary gamma radiation and the indicator of dispersed gamma radiation, coal layers possessing an irregularly low density in comparison with adjacent rock strata are accurately indicated by maxima on diagrams recording the intensiveness of the dispersed gamma radiation.

The possibility exists of using radioactive methods in prospecting for such minerals as boron, manganese, mercury, aluminum, copper, cobalt, beryllium, and gold. The short period of the semidisintegration of aluminum (2.3 min) and its rather high activation cross section (0.21 barn) make it entirely feasible to prospect for bauxite and evaluate its aluminum content by the radioactivation method.

The use of radioactive methods of searching for and extracting petroleum has already led to significant economy because of more accurate well drilling, the identification of gas- and oil-bearing layers, improvement in the means of observing the working of oil and gas deposits, and elimination of the heavy expenditures entailed in repairing wells with inadequate foundations.

The broadest application of radioactive isotopes is found in the metallurgical industry. Thus a number of plants conduct research work on the blasting process, specifically, investigation of the wearing of the fireresistant lining of the hearth bottoms and stacks of blast furnaces, as well as investigation of charging materials and gases in blast furnaces.

In steel smelting, research has been conducted in such areas as the thermodynamics of the reactions of the interaction between smelted iron and slag, the thermodynamic characteristics of elements dissolved in liquid iron, kinetics of the processes of slag formation, the kinetics of the reactions of isotope exchange, the phenomena of electrical transfer in molten slag, and others. This type of research has made it possible to find a number of thermodynamic values characterizing the allocation of phosphorus, sulphur, chrome, molybdenum, and wolfram between iron and slag in accordance with composition and temperature. Radioactive isotopes are used to great effect in investigating the properties of solutions of sulphur, phosphorus, chrome, silicon, and other elements in molten iron. Investigation of the kinetics of the processes of the elimination of phosphorus and sulphur from metal in producing slag has made it possible to arrive at kinetic equations describing the processes of the dephosphorization and desulphurization of pig iron and steel, and has brought to light factors controlling the speed of the separation of a metal from an admixture.

The production of a steel with a minimum content of nonmetallic matter is one of the most important requirements of quality metallurgy. To resolve this problem, the sources must be determined of the incidence of nonmetallic ingredients in the smelting and casting of steel. This problem is being studied in several plants with the aid of the radioactive isotope of calcium, used to "bombard" the lining of the casting bucket, the pouring spout, the siphoning material, and also the slag. The subsequent discharge of ingredients from the finished steel and the measurement of their radioactivity present a direct quantitative picture of the sources of metal pollution. Study of the nature of slag ingredients in smelting steel has shown that they are formed as a result of the metal drawing in: slag swirling on its surface in the casting mold, and also as a result of the washing out of the siphon tubing. Study of the hydrodynamic condition of the liquid phases in the metal bath of an open-hearth furnace, conducted with the aid of the radioactive isotope of cobalt, has led to determination of the proper speed of motion of metal and establishment of the turbulence of metal movement in the presence of rapid carbon oxidation.

Research has led to the resolution not only of problems of a scientific character, but also of problems of the technology of metallurgy. For example, the use of data on the hydrodynamics of the steel puddling furnace and the kinetics of slag formation has made it possible to shorten the period of smelting in open-hearth furnaces by 20 to 40 minutes, which in turn leads to an increase of 5 to 10 percent in the productivity of furnaces. Research on the sources of the contamination of steel by non-metallic ingredients has yielded technological methods of lowering the content in metal. Research on the behavior of sulphur in the open-hearth furnace when fuel with a high sulphur content is used, has in many plants created the necessary conditions for the production of steel with a minimum sulphur content.

As a result of studies on the movement of the charge in blast furnaces (the velocity of the charge and its components according to the size and height of the stack), measures have been proposed for a reconstruction of furnaces that would raise productivity by 10 to 20 percent. Control of the scouring of blast-furnace walls, achieved with the aid of radioactive isotopes, has made it possible to eliminate the damage caused by scouring and, consequently, to reduce unproductive stoppages and irretrievable losses of pig iron.

As regards searching for methods of improving the work of open-hearth furnaces, of special interest is the study of the kinetics of steel production, especially in the process of smelting scrap. In order to raise the quality of the steel and alloys produced in open-hearth and electric smelting furnaces, investigation of the sources of metal contamination is required. Important here is an examination of the problems of the transfer of the sulphur from gases into the metal, and that of nonmetallic and slag particles into the finished ingots. Also important is investigation of steel refining as regards such deleterious ingredients as phosphorus, sulphur, and oxygen; and of the kinetics of their transfer from the molten iron into the slag. Resolution of the task of

producing homogeneous metal ought to be assisted by research on the hydrodynamics of steel puddling furnaces, the kinetics of the crystallization of steel ingots, and the distribution of elements in ingots. Laboratory research in the field of the thermodynamics of smelted metal and slag, and investigation of the diffusion of the distributed mass and electrical transfer in fused metal, should also contribute to theory of the processes of steel production.

In the production of pig iron, research is directed toward raising the productivity of blast furnaces, particularly as regards investigation of the drift of the charge and the velocity of gas motion. Also promising is investigation of wear in the linings of metallurgical furnace aggregates. An especially important development is the use of radioactive isotopes in analyses of the raw materials and products of the metallurgical industry, and the working out of methods of high-speed analyses of the metallurgical processes. Another important trend is the use of radioactive isotopes in checking the accuracy of methods of chemical analyses. Also of promise is the use of activated analysis (using neutrons) in high-speed measurement under factory conditions.

With the use of radioactive isotopes in metalworking and the physics of metals it has become possible to study self-diffusion and diffusion in metals and alloys. This has great significance for a better understanding of interatomic linking, phased transformations, and the processes occurring in metals and alloys in the presence of varied conditions of equilibrium and the influence of various factors (composition, temperature, pressure, etc.). There is a great deal of interest attached to research on reactions in solids: oxidation processes, phased transformations in alloys, etc. Experimental data have been accumulated on self-diffusion in refractory metals, establishing the fact that alloying elements exert considerable influence on the self-diffusion of atoms in the base of an alloy. This is important for an understanding of the processes occurring in alloys at high temperatures, for development of the theory of alloying, and in searching for new alloys. The basic result of this research has been the establishment of the role of internal grain structure in the processes of self-diffusion and diffusion. This has led to an understanding of the nature of the influence of the preceding phased transformations on the qualities of alloys at increased temperatures. With the aid of tagged atoms it is now possible to expand greatly research on the elasticity of the vapor of metals and alloys, to study the thermodynamic characteristics and nature of interatomic relationships, and also to improve methods of determining the number of transfers in the passage of electrical current. This has greatly increased the possibilities of studying the electronic structure of solids.

Radiographic methods are widely used in the study of the heterogeneity of the macro- and microstructure of metals and alloys. Microradiography is also employed in studying diffusion phenomena on the boundaries of and within grain structures. Research with the aid of microradiography on the distribution of elements and diffusion on the boundaries of grains is attracting much interest in the investigation of the processes of the disintegration of metal products under different conditions.

Important data have been gathered on the influence of low energy radioactive radiation on the surface properties of metals. Specifically the radiation of zinc, aluminum, gold, platinum, beryllium, and Armco iron, with gamma quanta of Co^{60} at a dosage of 0.02 r/min/cm^2 increased surface resistance and reduced wear due friction. Thus, in zinc models resistance was increased by 1.5 times; the wear after friction sliding of carbonized steel models decreased by nearly 3 times after radiation with a dosage of 0.6 r/cm^2 . In these experiments it was demonstrated that the increased surface resistance and decreased wear of many metals reach their maximum at a depth of 0.4-0.5 mm from the surface. Interesting results were obtained in the radiation of bronze with beta particles (C^{14}). Here substantial hardening was observed at a depth of 0.3-1.0 micromillimeters. Wear in the zone of maximum hardening decreased by 3 to 4 times. This research points to new possibilities in the use of nuclear radiation for increasing the durability of metals.

In order to develop the theory of thermdurability and obtain relevant data in the search for alloys, it is necessary to investigate diffusion within and on the boundaries of the grain in refractory alloys, the electrolytic transfer of carbon and alloying elements in steel, and compression and plastic deformation in diffusion in metal and alloys. It is also necessary to do research on methods of autoradiography as regards the distribution of elements and the microvolume of alloys. In this connection it is highly desirable to carry out work to improve methods of autoradiography with a view to raising its resolving capacity. In particular, the method of neutron autoradiography must be improved and mastered.

In order to clarify the nature of interatomic relationships and the mechanism of atomic transmutations in solids, it is necessary to investigate diffusion in the monocrystals of metals and alloys. Related to this type of research is work on the analysis of the neutron structure, which in turn makes relevant investigation of structural changes in industrially important alloys. Of importance is research on phased transformations in alloys, in connection with which it would be expedient to investigate the influence of nuclear reactions on phased transformations. Here it will be necessary, first of all, to study the influence of high-speed neutrons on open-hearth transformations in steel.

In the field of machine building, radioactive isotopes are used in studying the phenomena of friction and wear. By this means studies have been conducted on the influence of various types of lubrication and fuel, load, velocity, and the dustiness of air on the wear of engine parts. Research has also been carried out on the anticorrosive effect of different additives in lubricating oil, etc. This has led to a sharp reduction of the time spent in testing machine parts, elucidated the effect of use factors on wear, and demonstrated that the protection of cylinder and piston parts from corrosion wear can be secured by motor-oil additives with different modes of action -- the capability of forming a protective antifriction film on the surfaces of friction areas, the capability of neutralizing corrosive acids. These researches have also revealed the processes occurring on the surfaces of metals in their reaction to additives, and have led to examination of the process of the protection of surfaces of friction areas from corrosion wear.

The further development of research on friction and lubrication should embrace the problems of finding suitable lubricants for frictional parts operating under high proportional loads in a broad temperature range in diverse conditions, and also new methods of testing lubricants.

Research on the processes of metal cutting is still being conducted with activated cutters in turning work. Further research in this direction should extend to other aspects of metalworking--grinding, milling, drilling, stretching, etc., not only as regards cutters, but also operating parts and lubricant-cooling liquids. In this research use should be made of nuclear particles in measurement, and also autoradiography.

In the field of the flotation and enrichment of ore the use of radioactive isotopes has led to many new discoveries in the study of the process of the interaction of reagents and minerals. At present there has been developed and successfully applied a method of quantitative microautoradiography which has led to quantitative evaluation of the degree of disproportionality of the distribution of xanthogenates on the surface of particles of sulfidic minerals in relation to the length of the hydrocarbon radical, the hydrogen index of the solution, and the concentration of oxygen and regulating reagents. It has also demonstrated the influence of the degree of disproportionality on the extraction of given minerals into flotation products. Similarly, the relationship between extraction and the degree of disproportionality in the distribution of the reagent has been determined in the flotation of a nonsulfide mineral (fluoride), when sodium tridecylate with C^{14} is used. Experiments conducted on the joint action of the xanthogenates of lower alcohols and increased dosages of frothing agents has led to the determination of the necessary conditions for increasing the flotation extraction of sulfidic minerals resistant to flotation--pyrotine and sphalerite into the foam product.

As regards the technical processes of ore enrichment, great interest is directed to the method of determining the different elements contained in ores and rock layers and having a sufficiently large effective cross section of nuclear reaction (alpha and eta). This method is based on the use of nuclear reaction (alpha, eta), in which neutrons are emitted during the radiation of an object with alpha particles from the isotope ^{210}Po . As research with this method has indicated, with the use of a small amount of product (1 g or less) the content of boron and aluminum in enriched ores and enriching products can be quickly and precisely determined.

Work on a large scale is being conducted in the field of instrument construction with a view to creating methods of control based on changes in the ionization, absorption, and reflection of alpha, beta, and gamma radiations. By these means practical application has been made of instruments measuring the density of liquids and metal slurry, the thickness of sheet materials and coverings, the level of liquid and granular media, and the weight of material per unit of area; instruments controlling the filling of opaque containers; instruments serving as pickups in automatic regulating systems in the metallurgical, coal, ore-enrichment, chemical, textile, food, and other industries.

The principal advantages of instruments the work of which is based on the use of radioactive isotopes and nuclear radiations are: detachment, the absence of the influence of external conditions on the source of radiation; the absence of the reciprocal influence of the control medium and the measuring operation itself; great stability; the long period of service of sources of radiation; swiftness of action; etc.

The use of radioactive means of control permits automatization of the process of technical control, which consequently substantially reduces the number of controllers, which at present comprises 20-30 percent and in automatized shops, up to 40 percent--of all production workers. As a result, the cost of radioactive means of automatization and control is low and can be covered in a period of 3 to 8 months. Therefore the use, for example, of such instruments as thickness meters for measuring the thickness of covering material nets a profit of about 700,000 rubles a year in one plant.

According to figures of the Economics Institute of the Academy of Sciences USSR, based on the research of 60 enterprises of metallurgy, steel rolling, machine building, petroleum drilling, food and perfume production, and other branches of industry, the use of radioactive instruments of control and automatization yielded a savings of 500,000,000 rubles in 1958. It has been estimated that the application of radioactive means of automatization and control in all similar enterprises of the Soviet Union will produce a savings of 4 billion rubles annually.

Further work in this direction should emphasize the standardization and coordination of instruments and the designing of Standard machine assemblies and units and assembly lines--the foundation of the automatization of the technological processes of industry.

There has been a substantial expansion of research with a view to developing new equipment based on the use of neutron current nuclear-radiation spectroscopy, certain nuclear reactions, and other achievements of contemporary physics. In this area the phenomena of the absorption, dispersion, and the slowing of the neutrons of the control medium can be successfully utilized. Neutron currents can be used for the automatic control of the composition of material, measurement of the moisture of various media, regulation of the level of hydrogen-containing media, temperature control, noncontact automatic control of the outflow of material moving through pipelines, etc. An example of the use of spectroscopic methods is an instrument for unilateral measurement of the thickness of material. Use of a scintillation receiver and special discriminators makes it possible to produce a spectrum of secondary radiation; this eliminates the necessity of using huge lead protective screens.

The gamma-defectoscopy of metals is the most important of the methods of using radioactive radiation in the control of machine parts and other metal products. At present about 2,000 gamma-defectosopes have been introduced in over 1,000 enterprises of the USSR. According to data of the Economics Institute of the Academy of Sciences USSR, the introduction of this method of control yielded in 1958 alone a savings of over 200,000,000 rubles. Besides the isotope of cobalt-60, several new radioactive isotopes with varying gamma-radiation energy have been employed: thulium-170, europium-152 and 154, cesium-137, cerium-144, and

others. Experience has been acquired in using them for control of the quality of welded, soldered, cast, and other thinshelled articles manufactured from alloys based on iron, titanium, aluminum, and magnesium. They have also been used in detecting flaws in machine units and aggregates.

The use of gamma radiation from betatrons has permitted extension of the limits of the thickness of controlled materials, in comparison with the use of radiation from radioactive isotopes. A substantial improvement of the ionization method of gamma-defectoscopy has made it possible to lower the cost of controlling, and, in a number of cases, to automatize the process. At present a great deal of work is being done with a view to devising defectoscopes which produce a direct image of the parts under radioscopy. In these instruments electronic-optical converters and complex electronic devices will be used.

In the field of the quality control of manufactured articles further research is required for the improvement of existing methods and the development of new methods. In this area attention must be given to reducing the amount of image blur to the minimum and the use of scintillation counters securing high sensitivity, efficiency, and automatization of the process of the control of manufactured parts. Work on the use of radioactive isotopes of Tu^{170} , Cs^{137} , Ir^{192} , Eu^{154} , Eu^{152} , Se^{75} , In^{192} , and others must be substantially expanded. It is also necessary to intensify work on the use of nuclear radiations for the control of products not only of metal but of other materials--ferroconcrete, light materials, graphite, etc.

With the aid of nuclear radiation, research has been successfully conducted on the hydrodynamic structure of liquid compounds moving by pipe (water-steam, water-carbon tetrachloride, water-mercury, water-coal, water-sand, and others). The data accumulated has permitted examination of the distribution in volume of liquid and gaseous phases in the presence of various loadings of the evaporation surface, diverse pressures, and the varying salt content of reactor water. Research work in this field should be continued. Further research should also attempt to accumulate data on the vapor content in the boundary layer with the aid of beta radiation, as regards both full boiling and the surface boiling of water heated to the saturation temperature.

The use of radioactive isotopes as tagged atoms has permitted the accumulation of a great deal of experimental data on the conditions of salt separation with vapor of high parameters and the crystallization of salts from the vapor solution on boiler heating surfaces and the vanes of steam turbines. This research is even more important for atomic electric-power stations with boiling-water reactors and direct action of the steam in the turbine, inasmuch as deposits in the latter may contain long-lived radio-active isotopes. Of importance as regards atomic electric-power stations is the loss along with steam of a very large number of compounds diverse falling into the reactor water, due not only to the pumping of the water cooling the turbine condenser, but also to the corrosion of equipment parts, and, in a number of cases, to the occurrence in the water of fusion products, specifically, soluble salts and other compounds of uranium, soluble products of stainless steel, zirconium, and other construction materials.

There are great prospects for scientific research with radioactive isotopes and radiation in the fields of hydrotechnics, soil mechanics, and engineering geology. In these important fields a methodology has been developed based on the absorption and dispersion of gamma radiations, which makes it possible to control solidity of the foundation structures of earth dams, to regulate the density of the pulp of suction dredges working on the alluvium of earth dams, and to conduct research work on the aeration of streams of suspended river alluvium.

With the use of radioactive isotopes of P^{32} , Rb^{86} , Na^{24} , I^{131} , and others, methods have been developed for studying the mechanics of the motion of liquids in porous media, which permit determination of the average velocity of the motion of liquids, the character of porosity, and the hydrodynamic and molecular processes occurring in a porous medium. Supplementing this work is research on water movement in peat, conducted with the use of the radioactive isotope S^{35} combined with Na_2SO_4 under laboratory and field conditions. These experiments have demonstrated that peat contains 35 to 40 percent water which does not take part in the filtration process.

Using hydrogen isotopes--tritium and deuterium--extremely interesting prospects lie before research workers in the field of the filtration and dynamics of underground waters.

Construction materials naturally are of great importance in hydro-technical construction. In this field, through the use of the radioactive isotope S^{35} , research has been conducted on the distribution of sulphate ions during capillary attraction in cement. This has shown that the amount of sulphate ions penetrating the material depends to a large degree on the structure. Research has also been carried out on the kinetics of the penetration of sulphate ions in concrete of varying composition. In this connection a research methodology has been worked out permitting determination of the depth of penetration and the character of the distribution within concrete of sulphate ions and other aggressive ions. These means, in combination with other methods of investigating the corrosion of concrete, make it possible to describe the influence of the structure and permeability of concrete on the penetration of sulphate solutions within concrete, and correspondingly, on the development of the processes of sulphate corrosion in concrete. As a result of this research it is possible to formulate the requirements for the density of concrete as regards assuring firmness and durability.

Through the use of a narrow beam of gamma radiation a method has been developed of determining the moisture content of building materials and of transferring moisture to them without disturbing the structure. In experiments conducted with porous concrete samples, it was shown that the divergence in determining their moisture content by gamma rays and by allowing them to dry out did not exceed 2% of the weighed moisture. In addition, interesting experiments have been conducted to determine the surface specificity of quartz and cement powders by the adsorption method based on investigation of the monomolecular adsorption of the radioactive isotopes of strontium, calcium, wolfram, cesium, and cobalt. Vol'skiy cement powders, clinker, and pure quartz crystal served as adsorbents.

Also in prospect is the use of radioactive isotopes radiation, and neutrons in the cement industry. Here it is necessary, first of all, to resolve such problems as the content of the hard component of slurry, the expenditure of slurry and gases, the moisture of gases, etc.

In the glass industry the radioactive isotopes Ca^{45} and Sr^{89} have been successfully used in investigating the hydrodynamics of molten glass in the baths of glass-smelting furnaces. Experiments have demonstrated that molten glass derived from a portion of charge introduced from any side of the furnace is distributed throughout the whole basin of the furnace in the form of separate masses moving at various speeds. The main current of the glass mass does not necessarily move away from the side in which the charge is introduced. It has also been discovered that in the furnace there is a small primary surface current of the glass mass moving over the whole basin of the furnace at a speed of about 60-70 meters per hour. From the pouring area to the area of the maximum temperature of the furnace two separate recurrent and advancing cycles of regular currents circulate. The first cycle takes about 45 minutes and the second about 5 hours. From the maximum-temperature area of the furnace to the finishing area there also exists a recurrent-advancing current located somewhat below the surface of the molten glass. Experiments have shown that the recent opinion holding that the glass derived from one charge is processed almost simultaneously in one mass does not correspond to reality.

The use of radioactive isotopes and nuclear radiation in scientific research and in the control and automatization of technical processes is virtually unlimited. In this short report only a few of the already-existing scientific applications in which these methods are widely used have been examined.

It should be noted that the introduction of technology and equipment based upon the use of radioactive isotopes and nuclear radiation has already yielded significant economic results in industry. Thus, according to data of the Economics Institute of the Academy of Sciences USSR the average annual saving resulting from the introduction of this technology and equipment amounted to 1.6 to 1.8 billion rubles in 1958.